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### C E R T I F I C A T I O N

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Hollywood, Florida



Birgit Bartell

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Lerner & Greenberg, P.A.  
P.O. Box 2480  
Hollywood, FL 33022-2480  
Tel.: (954) 925-1100  
Fax.: (954) 925-1101

Description

Method for operating a switch in a free-running switch mode power supply, and a drive circuit for a switch in a free-running switch mode power supply

The present invention relates to a method for operating a switch in a free-running or quasi-resonant switch mode power supply as claimed in the features of the precharacterizing clause of claim 1, and to a drive circuit for operating a switch in a free-running switch mode power supply as claimed in the features of the precharacterizing clause of claim 13.

Free-running switch mode power supplies have been known for a long time for supplying DC voltages to loads, such as computers, monitors, televisions or the like. The basic design and the method of operation of such switch mode power supplies are described, for example, in DE 197 32 169 A1. Integrated circuits are normally used for operating the switch which is provided to control the power consumption in such power supply units, such as drive modules of the TDA 4605 or TDA 16846 type, which are available from the Applicant.

In order to assist understanding of the invention which will be explained in the following text, the basic design and the basic method of operation of a conventional free-running flyback converter switch mode power supply will first of all be explained, with reference to Figures 1 and 2.

The switch mode power supply has input terminals EK1, EK2 for application of a rectified input voltage  $U_{in}$ , and output terminals AK1, AK2 for providing an output voltage  $U_{out}$  for a

load. A transformer  $Tr$  is provided to convert the input voltage  $U_{in}$  to the output voltage  $U_{out}$ , with the primary coil  $L_p$  of this transformer  $Tr$  being connected in series with a semiconductor switch  $T_1$  between the input terminals  $EK_1$ ,  $EK_2$ , and its secondary coil  $L_s$  being connected via a rectifier arrangement  $GL$  to the output terminals  $AK_1$ ,  $AK_2$ . In a flyback converter switch mode power supply such as this, the primary coil  $L_p$  draws energy from the input voltage  $U_{in}$  while the switch is closed, and emits this energy to the load via the secondary coil  $L_s$  and the rectifier arrangement  $GL$  when the switch  $T_1$  is subsequently closed.

The object of power supply units such as these is to keep the output voltage  $U_{out}$  largely constant irrespective of fluctuations in the power consumption of the load. A control loop is provided to control the output voltage or the power consumption of the switch mode power supply and has a control signal  $RS$  which is derived from the output voltage  $U_{out}$  and governs the power consumption of the switch mode power supply. This control signal  $RS$  is supplied to a drive circuit  $IC$ , which provides a drive signal  $AS$  for operating the switch in a clocked manner.

The drive signal comprises a sequence of drive pulses, with the time duration of the individual drive pulses, that is to say the time for which the switch is switched on, being dependent on the control signal and rising as the power consumption of the load rises, in order to keep the output voltage  $U_{out}$  constant. The times at which the switch  $T_1$  is closed in a free-running/quasi-resonant switch mode power supply are governed by times at which the primary coil  $L_p$  has emitted the previously stored energy to the secondary  $L_s$ , and is thus demagnetized. Magnetization states of the primary coil such as these are detected by means of an auxiliary coil  $L_h$ ,

which is coupled to the primary coil and is likewise connected to the drive circuit IC.

By way of example, Figure 2 shows the time profile of a drive signal AS, the power consumption  $P_{in}$  and the magnetization  $M$  of the primary coil  $L_p$ , with these signal profiles in each case being shown for a first value of the control signal RS in the left-hand part, and for a second value of the control signal RS in the right-hand part. The first control signal value RS results in switched-on durations of length  $t_{on1}$ , and the second control signal value results in switched-on durations of length  $t_{on2}$ .

When the switch  $T_1$  is closed, an input current  $I_{in}$  in each case rises linearly, starting from zero. The power consumption  $P_{in}$  is proportional to the current drawn and has the ramp-shaped profile as illustrated, assuming that the input voltage  $U_{in}$  is constant. In a corresponding way, the magnetization  $M$  rises linearly after being switched on and falls linearly once again after being switched off, during the time periods  $t_{off1}$ ,  $t_{off2}$ , with the switch  $T_1$  being switched on again when the magnetization has decreased to zero. The demagnetization time is in this case proportional to the magnetization time.

A drive cycle  $T$ ,  $T'$  is governed by the time duration between the start of two successive switching-on pulses. The energy which is consumed by the switch mode power supply is proportional to the area under the curve of the power consumption  $P_{in}$  and is proportional to the area under the curve of the magnetization  $M$ . The mean power consumed is obtained from the energy consumed in each drive cycle. On the assumption that the input voltage  $U_{in}$  is constant for at least a number of drive cycles, this mean power level is

proportional to the switched-on duration  $t_{on1}$ ,  $t_{on2}$ , and is thus proportional to the control signal RS.

In contrast to the situation in switch mode power supplies with fixed clocking, the instantaneous switching frequency in free-running quasi-resonant switch mode power supplies varies with the power consumption of the load, with the information about this power consumption being fed back via the control signal to the drive circuit for the switch. Free-running switch mode power supplies are therefore advantageously used in particular in televisions where, owing to the constantly changing picture information and the dynamic range of the audio signal, the load varies continuously, so that the switching frequency of the power supply unit also varies continuously and electromagnetic interference from the switch mode power supply on narrowband receiving circuits, such as tuners etc., in each case acts for only a short time and does not lead to interference with the picture.

A further advantage of free-running flyback converter switch mode power supplies is their high efficiency. They are therefore increasingly being used for compact power supply units in enclosed plastic housings, since the maximum amount of heat which can be emitted from housings such as these is severely limited. In the case of loads such as Notebooks, flat screens, chargers and electronic musical instruments, the power consumption may remain constant over a lengthy time period, which means that the operating frequency of the switch mode power supply also correspondingly remains constant over a lengthy time period. This can result in high level peaks at specific frequencies, which necessitate additional suppression filters in order not to exceed the maximum permissible values for the emitted radiated electromagnetic interference.

The aim of the present invention is to provide a method for operating a switch, which controls the power consumption, in a free-running switch mode power supply, and to provide a drive circuit for a switch, which controls the power consumption, in a free-running switch mode power supply, with the effects of emitted radiated electromagnetic interference being reduced, without any complex shielding measures being required for this purpose, even when the power consumption of a load which is connected to the power supply unit remains constant for a lengthy time period.

This aim is achieved by a method as claimed in the features of claim 1, and by a drive circuit as claimed in the features of claim 14. Advantageous refinements of the invention are the subject matter of the dependent claims.

The method according to the invention for operating a switch, which is connected in series with a primary coil of a transformer, in a free-running switch mode power supply, in which a control signal which governs the power consumption is produced, results in the provision of a modulation signal and the production of a drive signal for the switch such that the drive signal has a recurrent pulse sequence with at least one first switching-on pulse with a first pulse duration and at least one second switching-on pulse, which follows the at least one first switching-on pulse in time and has a second pulse duration, with the pulse duration of at least one of the switching-on pulses being modulated on the basis of the modulation signal within a range which is predetermined by the control signal. The overall time for which the at least one first switching-on pulse and the at least one second switching-on pulse are switched on in the recurrent pulse sequence is in this case chosen to be dependent on the control signal, such that a mean power level which is consumed via the

input terminals in each pulse sequence remains at least approximately constant, assuming that the control signal remains the same.

As was explained in the introduction, the energy which is consumed in each drive cycle, that is to say per drive pulse or switching-on pulse, in a free-running switch mode power supply is dependent on the time for which the switch is switched on. While a drive signal with periodically recurrent switching-on pulses with the same pulse duration is produced in conventional free-running switch mode power supplies, assuming that the power consumption is constant, a drive cycle with the method according to the invention comprises at least two switching-on pulses, with the pulse duration of one of the two pulses varying on the basis of the modulation signal, even when the control signal remains the same from one drive cycle to the next, and the pulse duration of the other switching-on pulse being matched to the modulated pulse duration of the first pulse, such that the mean power level which is consumed in each drive cycle is at least approximately constant. The times for which the at least one first and second pulse are switched on are preferably matched to one another such that any fluctuation in the mean power level consumed per drive cycle fluctuates by less than 1% in each drive cycle with respect to a mean consumed power level determined over two or more drive cycles.

The fact that the pulse duration of the first and second switching-on pulses varies from one drive cycle to the next means that the switching frequency of the switch which is connected in series with the primary coil in the switch mode power supply in the method according to the invention varies from one drive cycle to the next, as a result of which emitted radiated electromagnetic interference is distributed over a

wider frequency range even when the power consumption remains the same, and, in particular, this avoids peaks in a narrow frequency band in the emitted radiated interference.

One embodiment of the invention provides for the pulse duration of the at least one first switching-on pulse to be chosen to be proportional to the control signal, and for the pulse duration of the at least one second switching-on pulse to be chosen to be proportional to the first pulse duration, with the proportionality factor via which the second pulse duration depends on the first pulse duration being modulated within predetermined limits by the modulation signal. The proportionality factor by which the second pulse duration is dependent on the first pulse duration and the range within which this proportionality factor is modulated by the modulation signal is preferably chosen such that the energy consumption during the second switching-on pulse is less than the energy consumption during the first switching-on pulse. The pulse duration of the second switching-on pulse can in this case be modulated in order to vary the switching frequency, with the fluctuations that result from this in the power consumption during the second switching-on pulse having only a minor effect on the mean power consumption.

The pulse sequence preferably comprises  $m$  first switching-on pulses with the first pulse duration and  $n$  second switching-on pulses with the second pulse duration, in order via this ratio  $m/n$  to set the proportion of the energy which is consumed during the second switching-on pulses to the energy which is consumed during the entire drive cycle. Preferably,  $m = 2$  and  $n = 1$ .

In the embodiment of the method according to the invention in which there are two first switching-on pulses and one second

switching-on pulse, the proportionality factor by which the second pulse duration depends on the first pulse duration is preferably between 0.3 and 0.5, and is varied within this range by the modulation signal.

The modulation signal which modulates the pulse duration of at least one of the switching-on pulses in the recurrent pulse sequence within predetermined limits is preferably a random signal or a pseudo-random signal.

The maximum power consumption of a free-running switch mode power supply is governed by the magnetic saturation of the transformer. In the method according to the invention, the maximum power consumption of the power supply unit is less since, owing to the desired time difference between the first and the second pulse duration, which is required for modulation of the switching frequency, saturation magnetization is not used, at least during one pulse in the pulse sequence of a drive cycle. In order to increase the maximum power consumption, one embodiment of the invention therefore provides for the range within which the time for which the at least one of the drive pulses in the recurrent pulse sequence is switched on, whose pulse duration is modulated by the modulation signal, to be made dependent on the maximum magnetization of the primary coil in each switching-on process. If this maximum magnetization in each switching-on process increases owing to an increased power consumption by the load, then this modulation range is reduced and tends to zero, when the required power consumption is so high that the maximum magnetization (saturation) of the transformer is reached. The drive signal is not frequency modulated by the modulation signal at all when the power consumption is at its maximum.

The drive circuit according to the invention for a switch, which is connected in series with a primary coil of a transformer, in a free-running switch mode power supply has a first input terminal for supplying a control signal which determines the power consumption of the power supply unit, a second input terminal for supplying a magnetization signal which is dependent on the magnetization state of the primary coil, an output terminal for providing a drive signal, a signal generating circuit to which the magnetization signal and a reference signal which is dependent on the control signal are supplied, and which provides a drive signal comprising a sequence of switching-on pulses, with the start of a switching-on pulse in each case being predetermined by the magnetization signal, and with the pulse duration of a switching-on pulse being predetermined by the reference signal. A reference signal generating circuit is provided in order to produce the reference signal, is supplied with the control signal and has a signal generator which provides a modulation signal. The reference signal generating circuit also has a weighting circuit, to which the control signal and the modulation signal are supplied and which provides a control signal that is weighted on the basis of the modulation signal, as well as a changeover switch, as a function of whose switch position the control signal or the weighted control signal is supplied as the reference signal to the signal generating circuit. Depending on the switch position of the changeover switch in the reference signal generating circuit, the signal generating circuit produces first switching-on pulses whose first pulse duration is dependent on the control signal, or second switching-on pulses are produced whose second pulse duration is dependent on the control signal weighted by means of the modulation signal. The modulation signal in this case governs the proportionality factor between the second pulse duration and the first pulse duration. The

changeover switch is operated, for example, by means of a counter which counts the switching-on pulses in the drive signal and switches the switch periodically in order in this way to produce a pulse sequence with a predetermined sequence pattern of first switching-on pulses and second-switching-on pulses. In one exemplary embodiment of the invention, the counter is designed such that it loads the switch for in each case two switching-on pulses in a switch position in which the control signal is supplied to the signal generating circuit, in order in this way to generate first drive pulses, and such that the switch is then switched for the duration of one switching-on pulse to a switch position in which the weighted control signal is supplied to the signal generating circuit, in order in this way to generate a second switching-on pulse.

The present invention will be explained in more detail in the following text using exemplary embodiments and with reference to figures, in which:

Figure 1 shows a circuit diagram of a free-running switch mode power supply according to the prior art,

Figure 2 shows time profiles of selected signals in a free-running switch mode power supply according to the prior art,

Figure 3 shows time profiles of a drive signal which comprises a recurrent pulse sequence with a first and a second switching-on pulse, and the magnetization caused by this drive signal in the primary coil of a transformer in a switch mode power supply, for three different drive cycles,

Figure 4 shows an illustration in the form of a graph of the switching frequency of the drive signal as a function of the

time difference between a first pulse duration and a second pulse duration for a drive signal as shown in Figure 3,

Figure 5 shows a schematic illustration of the variation of the first and second pulse durations as a function of the control signal,

Figure 6 shows a schematic illustration of an arrangement for determining the first and second pulse durations as a function of the control signal and of the modulation signal,

Figure 7 shows a time profile of a pulse sequence with two first switching-on pulses with a first pulse duration and with one second switching-on pulse with a second pulse duration (Figure 7a), and the time profile of the magnetization of the primary coil resulting from such a pulse sequence (Figure 7b),

Figure 8 shows a diagram of the power consumed by a free-running switch mode power supply as a function of the first pulse duration and of the second pulse duration for a pulse sequence as shown in Figure 7a,

Figure 9 shows a detail of the circuit diagram of a free-running switch mode power supply with a drive circuit according to the invention for producing a drive signal for a switch, which is connected in series with a transformer, in the power supply unit, and

Figure 10 shows time relationships for the production of a switching-on pulse.

Unless stated to the contrary, identical reference symbols denote identical components and signals with the same meaning in the figures. With regard to the basic design of a free-

running switch mode power supply, the following explanation of the method according to the invention and of a drive circuit according to the invention refer to Figure 1, including the reference symbols used in that figure.

The method according to the invention for operating a switch, which is connected in series with a primary coil of a transformer, in a free-running switch mode power supply provides for the switch T1 to be operated by means of a drive signal AS which comprises a recurrent pulse sequence having at least one first switching-on pulse with a first pulse duration and at least one second switching-on pulse with a second pulse duration, with at least one of the pulse durations being modulated as a function of a modulation signal.

Figure 3 shows time profiles of a drive signal AS which has a recurrent pulse sequence with a first switching-on pulse and a second switching-on pulse, and the magnetization M of the primary coil Lp resulting from these pulse sequences. Figure 3 shows the pulse sequence of the drive signal for three drive cycles, with the pulse sequences in the individual drive cycles being shown differently, in order to distinguish between the pulse sequences. AS(1) denotes the pulse sequence during a first drive cycle, AS(2) denotes the pulse sequence during a second drive cycle, and AS(3) denotes the pulse sequence during a third drive cycle. The profile of the magnetization M and of the pulse sequence during the first drive cycle are shown by solid lines in Figure 3, the profile during the second drive cycle is shown by dashed lines, and the profile during the third drive cycle is shown by dashed-dotted lines. The numbers (1), (2) and (3) are used to distinguish between the signals during the individual drive cycles, as will be explained in the following text.

In the example, each of the pulse sequences comprises a first switching-on pulse P1 and a second switching-on pulse P2, which follows the first switching-on pulse P1 in time. The primary coil Lp is magnetized and is then demagnetized during the respective switching-on pulse, with the demagnetization duration being proportional to the duration of the respective switching-on pulse. The duration of the switching-on pulse P1 plus the subsequent demagnetization time is referred to in the following text as the first pulse duration T1, and the duration of the second switching-on pulse P2 plus the subsequent demagnetization time is referred to in the following text as the second pulse duration T2. Tp denotes the period duration of the pulse sequence with the first switching-on pulse P1 and the second switching-on pulse P2, and, in the illustrated example, results from the first pulse duration T1 plus the second pulse duration T2.

In the exemplary embodiment illustrated in Figure 3, the first pulse duration T1 is modulated within predetermined limits from one drive circle to the next on the basis of a modulation signal. The energy which is consumed on the basis of the first switching-on pulse P1 is proportional to the area of the magnetization curve, which has a triangular profile, where M1 in Figure 3 denotes that section of the magnetization curve which results from the first switching-on pulse, and M2 denotes that section of the magnetization curve which results from the second switching-on pulse P2. This energy, which corresponds to the integral under the magnetization curve, can be expressed as follows:

$$W = \frac{1}{2} \cdot a \cdot T1^2 + \frac{1}{2} \cdot a \cdot T2^2 \quad (1)$$

where W is the energy and a is a constant which takes account of the gradient of the magnetization curve and circuitry

constants, such as the inductance of the transformer and the input voltage  $U_{in}$ .

The mean power level  $P_m$  consumed in each drive cycle is given by:

$$P_m = W/t_p \quad (2)$$

where this mean power level to be consumed is governed by the power consumption of the load, and the information about this power consumption is contained in the control signal RS. The time duration  $T_2$  of the second switching-on pulse  $P_2$  in the method according to the invention is thus matched to the time duration  $T_1$  of the first switching-on pulse  $P_1$  such that the mean power level  $P_m$  which is consumed remains constant, assuming that the control signal RS remains the same. The value of the second pulse duration for each value of the first pulse duration  $T_1$  as modulated by the modulation signal can be determined quite easily from the above equations (1) and (2). The fundamental effects of the variation of the first pulse duration  $T_1$  on the second pulse duration  $T_2$  while the mean power level  $P_m$  which is consumed remains the same are shown in Figure 3. The solid line for the magnetization curve shows a first switching-on cycle with a first pulse duration  $T_1(1)$  and a second pulse duration  $T_2(1)$ . If the first pulse duration is increased by virtue of the modulation, as is illustrated in the dashed profile for the second drive cycle, then the power consumption during the first switching-on pulse  $P_1$  is thus correspondingly increased. The second pulse duration  $T_2$  is correspondingly reduced, in order to keep the average power consumed throughout the entire period  $t_p$  constant. When the second pulse duration  $T_2$  is determined on the basis of the equations (1) and (2), this takes account of the fact that a reduction in the second pulse duration  $T_2$  reduces the energy

consumption during the second switching-on pulse  $P_2$ , but that this also results in a reduction in the total duration  $T_p$  by a time period  $\Delta T(1)$  in comparison to the situation shown by the solid lines.

If the first pulse duration is reduced, as is illustrated by the dashed-dotted lines for the third drive cycle, then the second pulse duration must be increased in order to keep the total amount of energy which is consumed during the period duration  $T_p(3)$  constant. In the illustrated example, this results in the period duration  $T_p(3)$  being lengthened in comparison to the period duration  $T_p(1)$ . The pulse durations  $T_1$  and  $T_2$  are in any case matched to one another such that the average power consumed during the period duration  $T_p$  is constant, with the period duration fluctuating in the explained manner as a result of the modulation, thus resulting in a frequency-modulated drive signal even when the control signal remains the same and the power consumption thus remains the same.

Figure 4 shows changes in the switching frequency  $f$  relating to a normalized difference between the first pulse duration  $T_1$  and the second pulse duration  $T_2$ . This clearly shows that modulation of the first pulse duration  $T_1$  and the matching, which results from this, of the second pulse duration  $T_2$  in order to maintain a constant mean power consumption results in frequency variations in the switching frequency of the drive signal. Emitted electromagnetic radiated interference, which results from the drive signal  $AS$ , is thus "smeared" over a predetermined frequency range with the method according to the invention, even when the power consumption of the load remains constant over a lengthy time period.

Figure 5 shows the fundamental dependency of the first pulse duration  $T_1$  and of the second pulse duration  $T_2$  on the control signal RS and on the power consumed by the load, respectively. This clearly shows that the first and second pulse durations  $T_1$ ,  $T_2$  increase as the control signal RS increases, in order to increase the power consumption, with the ratio of the pulse durations  $T_1$ ,  $T_2$  to one another being such that the second pulse duration  $T_2$  is shortened when the first pulse duration  $T_1$  is lengthened, and vice versa, in order to keep the mean power consumption constant.  $\Delta t$  in Figure 5 denotes the time difference between the first pulse duration  $T_1$  and the second pulse duration  $T_2$ . This time difference is preferably reduced as the power consumption increases and the control signal RS in consequence becomes greater, until the first and second pulse durations  $T_1$ ,  $T_2$  are of equal duration at the maximum power consumption, in order to make it possible to utilize the maximum power consumption of the power supply unit, which is limited by the saturation of the transformer.

The power consumption of the switch mode power supply is governed by the first pulse duration  $T_1$  and the second pulse duration  $T_2$ , with at least one of the pulse durations being modulated by a modulation signal MS. The power to be consumed and hence the overall time for which the switch is switched on in each drive cycle are governed by the control signal RS.

Figure 6 shows a processing unit 10, to which the control signal RS which governs the power consumption as well as a modulation signal MS which modulates the pulse duration of at least one of the switching-on pulses are supplied, and the first and second pulse durations  $T_1$ ,  $T_2$ , from which the control signal RS and the modulation signal MS are determined. This processing unit 10 may, for example, contain a look-up table, containing two associated pairs of values for the first

pulse duration T1 and for the second pulse duration T2 for various control signals and various modulation signals. The processing unit 10 may also be in the form of a calculation unit, which determines the second pulse duration on the basis of the equations (1) and (2) explained above, for a predetermined control signal RS and a first pulse duration that is governed by the modulation signal MS.

Figure 7a shows a pulse sequence which comprises two first switching-on pulses P1 with the pulse duration T1, and a second switching-on pulse P2 with the pulse duration T2. Figure 7b shows the magnetization profile of the primary coil Lp for a pulse sequence such as this during one drive cycle. The mean power level Pin consumed by the free-running switch mode power supply is illustrated schematically in Figure 8, and is dependent on the first pulse duration T1 and on the second pulse duration T2. Figure 8 shows a number of elliptical curves, with the mean power consumed on each of these curves being constant, and with the power consumption increasing as the distance between the respective curve and the origin increases. The curves which are illustrated in Figure 8 clearly show that the first and second pulse durations T1, T2 can fluctuate within a wide range in order to achieve a predetermined mean power consumption, and in which case the associated second pulse duration T2 for each first pulse duration T1 can be determined from the curves. The curve which is illustrated in Figure 8 may, for example, be stored in the form of a table in an arrangement 10 as shown in Figure 6, in order, by way of example, to determine the associated second pulse duration T2 for a first pulse duration T1 which is modulated, for example, by a modulation signal.

One embodiment of the invention provides for the first pulse duration T1 to be set as a function of the control signal RS,

and hence matched to the power consumption of the load, and for the second pulse duration  $T_2$  to be chosen to be proportional to the first pulse duration  $T_1$ , with this proportionality factor varying as a function of a modulation signal within predetermined limits, so that the total switched-on time is dependent not only on the control signal  $RS$  but also on the modulation signal  $MS$ , in order to provide frequency modulation for the drive signal.

Starting from the origin, Figure 8 shows three radially running lines, with one of the lines showing the values for the power consumed when the second pulse duration  $T_2$  is 0.3 times or 30% of the first pulse duration  $T_1$ , the second pulse duration is 0.4 times or 40% of the first pulse duration  $T_1$ , and the second pulse duration  $T_2$  is 0.5 times or 50% of the first pulse duration  $T_1$ . If the elliptical power curves in the region between these lines are considered, then it can be seen that the power curves run approximately horizontally in this area, which means that, for a predetermined value of the first pulse duration  $T_1$ , fluctuations in the second pulse duration  $T_2$  within a range which is between 30% and 50% of the first pulse duration  $T_1$  do not result in any significant change to the mean power consumption. This is made use of in the embodiment which has been mentioned, in which the first pulse duration  $T_1$  is set exclusively as a function of the control signal  $RS$  and the second pulse duration  $T_2$  is set exclusively as a function of the first pulse duration  $T_1$  and of a modulation signal, with the modulation signal governing the fluctuation range of the second pulse duration  $T_2$ . This fluctuation range preferably covers a range between 30% and 50% of the first pulse duration for a pulse sequence with two first switching-on pulses and one second switching-on pulse.

The time sequence of the first switching-on pulses P1 and of the second switching-on pulse P2 within the pulse sequence may, of course, be varied as required, and is not dependent on the sequence illustrated in Figure 7a.

There may, of course, be any desired number of m first pulses M1 and n second pulses P2, which form recurrent pulse sequences in time, with different power curves being produced for each of these combinations, resulting in different variation ranges, within which the second pulse duration can be varied independently of the first pulse duration, without needing to significantly vary the mean power consumption.

Figure 9 shows a drive circuit 20 for a switch T1 which is connected in series with a primary coil Lp of a transformer Tr in a free-running circuit section, which drive circuit 20 produces a drive signal AS with a recurrent pulse sequence which comprises at least one first switching-on pulse and at least one second switching-on pulse. The pulse duration of one of the pulses is in this case set to be dependent on a control signal RS, and the pulse duration of the other pulse is dependent on the one pulse duration and is modulated by a modulation signal MS.

The drive circuit 20 has a first connecting terminal K1 to which a control signal RS is applied, which determines the power consumption of the power supply unit. This control signal RS is determined from the output voltage Uout in a manner which has been known for a long time, and as has been explained above, by way of example, with reference to Figure 1. In the example shown in Figure 9, this control signal RS is provided by a regulator RL, to which a reference voltage Vref and a feedback signal FS, which is dependent on the output voltage Uout, are supplied, and which determines any

difference between the reference signal  $V_{ref}$  and the feedback signal  $FS$ . The regulator  $RL$  is, by way of example, a proportional regulator, a proportional integral regulator, or an integral regulator. The control signal  $RS$  in the example being explained becomes greater the higher the power consumption of a load which is connected to the output terminals  $AK1$ ,  $AK2$ , with this power consumption being determined on the basis of the differences between the output voltage  $U_{out}$  and the reference value  $V_{ref}$ .

The drive circuit  $20$  has a second input terminal  $K2$ , to which a magnetization signal  $S21$  is supplied. This magnetization signal is determined by means of an auxiliary coil  $Lh$ , which is coupled to the primary coil  $Lp$ , and a comparator  $KMP$ , with this comparator  $KMP$  comparing the voltage across the auxiliary coil  $Lh$  with a reference ground potential, to which the input voltage is also related, and producing a rising flank in the magnetization signal  $S21$  once the voltage across the auxiliary coil  $Lh$  has fallen to the reference ground potential  $GND$  after demagnetization of the primary coil  $Lp$ .

The drive circuit  $20$  has a conventional signal generating circuit with a driver circuit  $212$ , which provides the drive signal  $AS$ , having an  $RS$  flipflop  $211$  and having a comparator  $210$ . The set input  $S$  of the flipflop  $211$  is in this case supplied with the magnetization signal  $S21$ , with the flipflop  $211$  being set by each rising flank of this magnetization signal  $S21$  in order in this way to switch on the power transistor  $T1$  which, in the example, is in the form of an  $n$ -channel MOSFET. The flipflop  $211$  is reset on the basis of an output signal from the comparator  $210$ , in order to switch off the transistor  $T1$ . In order to produce this reset signal, the minus input of the comparator  $210$  is supplied with a reference signal  $S22$  (from a reference signal generating circuit  $22$

which is still to be explained) and with a ramp signal S24. This ramp signal S24 is proportional to the input current  $I_{in}$ , which is likewise in the form of a ramp when the transistor T1 is closed, and, in the exemplary embodiment, is available in the form of a voltage across a resistor  $R_s$  that is connected in series with the primary coil  $L_p$ . The ramp signal S24 starts at zero when the transistor T1 is switched on, and rises linearly with time, with the flipflop 211 being reset in order to switch off the transistor T1 when the ramp signal S24 rises above the reference signal S22.

Figure 10 shows, schematically, the relationship between the gradient of the ramp signal S24, the amplitude of the reference signal S22 and the time  $t_{on}$  for which the transistor T1 is switched on. This clearly shows that the switched-on duration  $t_{on}$  is directly proportional to the reference signal S2, assuming that the gradient of the ramp signal S24 is constant. The gradient of the ramp signal S24 is once again dependent on the input voltage  $U_{in}$ , although this can be assumed to be constant, at least over a large number of drive cycles. If the input voltage  $U_{in}$  increases, then the control signal RS decreases, in order in this way to keep the power consumption constant.

In order to provide the reference signal S22, the drive circuit 20 has a reference signal generating circuit 22 with a signal generator 221 (which provides a modulation signal MS) and a weighting circuit 222. The reference signal generating circuit 22 also has a changeover switch 223 which, operated by a counter device 220, provides either the control signal RS or a weighted control signal S23 (which is provided by the weighting circuit 222) as the reference signal S22. The weighting circuit 222 has a voltage divider 222, which divides the control signal RS and has a tap at which the weighted

control signal S23 is produced. Depending on whether the control signal RS or the signal S23 is used as the reference signal S22 for determining the switched-on duration in the signal generating circuit 21, switching-on pulses are produced at the output of the signal generating circuit, whose duration is proportional to the control signal RS, or switching-on pulses are produced whose duration is proportional to the weighted signal S23. If the signal profile has two first pulses P1 and one second pulse P2, the variation range within which the signal S22 can vary on the basis of the modulation signal MS is produced as illustrated in Figure 8, such that the signal S23 has an amplitude which corresponds to between 30% and 50% of the amplitude of the control signal RS. In this case, the counter circuit 220 is designed such that it leaves the changeover switch 223 in a switch position in which the control signal RS is supplied as the reference signal S22 to the signal generating circuit 21 for the duration of two switching-on pulses in each case, in order to produce two first switching-on pulses P1 with a duration which is dependent on the control signal RS, and such that, after this, it changes the switch 223 for the duration of one switching-on pulse to a switch position in which the weighted control signal S23 is supplied as the reference signal S22 to the signal generating circuit 21, in order to produce a second switching-on pulse P2.

With other pulse sequences, in which a different number of first pulses are used and in which a different number of second pulses are used, the counter 220 is designed such that the changeover switch 223 is switched in order to achieve the desired pulse sequence.

List of reference symbols

20	Drive circuit
21	Signal generating circuit
210	Comparator
211	RS flipflop
212	Driver circuit
22	Reference signal generating circuit
220	Counter
221	Signal generator
222	Weighting circuit
223	Changeover switch
AK1, AK2	Output terminals
AS	Drive signal
C1	Capacitor
D1	Diode
EK1, EK2	Input terminals
f	Frequency
FS	Feedback signal
GL	Rectifier arrangement
GND	Reference ground potential
IC	Drive circuit
Iin	Input current
KMP	Comparator
LH	Auxiliary winding
Lp	Primary coil
Ls	Secondary coil
Ms	Modulation signal
OK	Optocoupler
P1	First switching-on pulse
P2	Second switching-on pulse
RL	Regulator
RS	Control signal
Rs	Resistor

S21	Magnetization signal
S22	Reference signal
S23	Weighted control signal
T1	First pulse duration
T1	Semiconductor switch
T2	Second pulse duration
Tp	Period duration
TR	Transformer
Uin	Input voltage
Uout	Output voltage
Vref	Reference voltage

Patent Claims

1. A method for operating a switch (T1), which is connected in series with a primary coil (Lp) of a transformer (Tr), in a free-running switch mode power supply, with an input voltage (Uin) being applied via the series circuit formed by the primary coil (Lp) and the switch (T1), with a secondary coil (Ls) of the transformer (Tr) being coupled to output terminals (AK1, AK2) at which an output voltage (Uout) is produced, a control signal (RS) which determines the power consumption being provided and the switch (T1) in each case being switched on when the primary coil (Lp) reaches a predetermined magnetization state,

characterized by

- provision of a modulation signal (MS),
- provision of a drive signal (AS) for the switch (T1) with a recurrent pulse sequence which has at least one first switching-on pulse (P1) with a first pulse duration and at least one second switching-on pulse (P2) with a second pulse duration, and with the pulse duration of at least one of the switching-on pulses (P1, P2) being modulated by the modulation signal (MS) within a range which is predetermined by the control signal (RS).

2. The method as claimed in claim 1, in which the overall time for which the switching-on pulses (P1, P2) are switched on, which is the sum of the times for which all the pulses in the pulse sequence are switched on, is dependent on the modulation signal (MS).

3. The method as claimed in claim 2, in which the relationships between the times for which the at least one first and second switching-on pulses (P1, P2) are switched on and the modulation signal (MS) are chosen such that a mean power level, which is recorded for each pulse sequence via the input terminals (EK1, EK2) is at least approximately constant assuming that the control signal (RS) remains the same.

4. The method as claimed in claim 2, in which the relationships between the times for which the at least one first and second switching-on pulse (P1, P2) are switched on and the modulation signal (MS) are chosen such that a mean power level which is recorded for each pulse sequence via the input terminals (EK1, EK2) is subject to fluctuations of less than 1% with respect to a mean value of the mean power level averaged over two or more pulse sequences, assuming that the control signal remains the same.

5. The method as claimed in one of claims 1 to 4, in which the first pulse duration of the first switching-on pulse is proportional to the control signal (RS) and the second pulse duration of the second switching-on pulse is proportional to the first switching-on duration, with a proportionality factor by which the second pulse duration is dependent on the first pulse duration being modulated within predetermined limits by the modulation signal (MS).

6. The method as claimed in claim 5, in which the limits within which the second pulse duration is varied are chosen such that the mean power level which is consumed by the switch mode power supply remains at least approximately constant, assuming that the control signal (RS) remains the same.

7. The method as claimed in claim 5, in which the limits within which the second switched-on duration is varied are chosen such that the mean power level which is consumed by the switch mode power supply is subject to fluctuations of less than 1%, assuming that the control signal remains the same.
8. The method as claimed in one of the preceding claims, in which the pulse sequence comprises m first switching-on pulses (P1) each having the first pulse duration, and n second switching-on pulses (P2) with the second pulse duration.
9. The method as claimed in claim 8, in which m = 2 and n = 1.
10. The method as claimed in claim 8 or 9, in which the range within which the second pulse duration is modulated by the modulation signal (MS) is between 0.3 times and 0.5 times the first pulse duration.
11. The method as claimed in one of the preceding claims, in which the modulation signal (MS) is a random or pseudo-random signal.
12. The method as claimed in one of the preceding claims, in which the range within which the switched-on duration of the at least one of the drive pulses (P1, P2) in the recurrent pulse sequence, whose pulse duration is modulated by the modulation signal, is dependent on the maximum magnetization of the primary coil in each switching-on process.
13. The method as claimed in claim 12, in which the difference between the first and the second pulse duration tends to zero when the power consumption is so high that the

maximum magnetization (saturation) of the primary coil (Lp) is reached.

14. A drive circuit for a switch (T1), which is connected in series with a primary coil (Lp) of a transformer (Tr), in a free-running switch mode power supply, which drive circuit has the following features:

- a first input terminal (K1) for supplying a control signal (RS) which governs the power consumption,
- a second input terminal (K2) for supplying a magnetization signal (S21) which is dependent on the magnetization state of the primary coil (Lp),
- an output terminal (AK) for providing a drive signal (AS),
- a signal generating circuit (21), to which the magnetization signal (S21) and a reference signal (S22) which is dependent on the control signal (RS) are supplied and which provides a drive signal (AS) comprising a sequence of switching-on pulses, with the start of a switching-on pulse in each case being predetermined by the magnetization signal (S21), and the duration of a switching-on pulse being predetermined by the reference signal (S22),

characterized by

a reference signal generating circuit (22), to which the control signal (RS) is supplied, which reference signal generating circuit (22) provides the reference signal (S22) and has the following further features:

- a signal generator (221) which provides a modulation signal (MS),

- a weighting circuit (222), to which the control signal (RS) and the modulation signal (MS) are supplied and which provides a control signal (S23) which is weighted on the basis of the modulation signal,

- a changeover switch (223), on the basis of whose switch position the control signal (RS) or the weighted control signal (S23) is provided as the reference signal (S22).

15. The drive circuit as claimed in claim 14, in which the reference signal generating circuit (22) has a counter (220) which operates the changeover switch (223) and counts the drive pulses in the drive signal (AS).

16. The drive circuit as claimed in claim 14 or 15, in which the weighting circuit has a signal divider (222) whose division ratio is set within predetermined limits by the modulation signal (MS), to which the control signal (RS) is supplied and which has a signal tap at which the weighted control signal (S23) can be tapped off.

## Abstract

Method for operating a switch in a free-running switch mode power supply, and a drive circuit for a switch in a free-running switch mode power supply

The present invention relates to a method for operating a switch, which is connected in series with a primary coil of a transformer, in a free-running switch mode power supply. The method comprises the provision of a modulation signal and the provision of a drive signal for the switch with a recurrent pulse sequence which has at least one first switching-on pulse with a first pulse duration and at least one second switching-on pulse with a second pulse duration, and with the pulse duration of at least one of the switching-on pulses being modulated by the modulation signal within a range of values which is predetermined by the control signal.